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ORIGIN OF THE ELECTRICAL FLUID THEORIES

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IN a previous paper an attempt was made to show how the hypothesis of an electric effluvium or an electric atmosphere, by means of which electrified bodies were supposed to exert an attraction or repulsion upon each other, played a prominent part in electrical theory for more than 150 years. In the meantime two kinds of electrification had been discovered, and this discovery greatly increased the difficulty of finding a satisfactory explanation of the phenomena of attraction and repulsion.

The discovery of electric induction by Stephen Gray was referred to in the previous paper. This discovery, along with many other important electrical discoveries, was made in 1729. In 1733, du Fay, a French officer and engineer, who had been repeating Gray's experiments, communicated to the Royal Society through the Duke of Richmond the first announcement of the discovery of two kinds of electrification, or, as he believed, two kinds of electricity. This letter was read before the Royal Society and is published in volume 38 of the Philosophical Transactions. In it du Fay describes a number of new electrical discoveries which he had made, some of them very important, as, for example, the fact that all solids when suitably insulated may be electrified by friction or contact with other bodies. Then he says:

> Chance has thrown in my way another Principle, more universal and remarkable than the preceding one, and which casts a new Light on the Subject of Electricity. This Principle is, that there are two distinct Electricities, very different from one another; one of which I call *vitreous Electricity,* and the other *resinous Electricity.* The first is that of Glass, Rock-Crystal, Precious Stones, Hair of Animals, Wool and many other Bodies; The second is that of Amber, Copal, Gum-Lack, Silk, Thread, Paper, and a vast Number of other Substances. The Characteristick of these two Electricities is, that a Body of *vitreous Electricity,* for Example, repels all such as are of the same Electricity; and on the contrary attracts all those of the *resinous Electricity*; so that the Tube made electrical, will repel Glass, Crystal, Hair of Animals, &c. when rendered electrick and will attract Silk, Thread, Paper, &c. though rendered electrical likewise. Amber, on the contrary will attract electrick Glass, and other Substances of the same Class and will repel Gum-Lac, Copal, Silk Thread, &c.
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> Two Silk Ribbons when rendered electrical will repel each other; Two Woollen Threads will do the like, but a Woollen Thread and a Silk Thread will mutually attract one another.

Du Fay justly regarded this newly discovered fact regarding electrification as capable of explaining many electrical phenomena which up to that time had been incapable of explanation. He does not propose any hypothesis as to the mechanism of attraction or repulsion, nor does he propose any theory as to the coexistence of the two kinds of electricity in the same body or have anything to say about their neutralizing each other when combined in suitable proportions. This part of the two-fluid theory seems to have been proposed by Robert Symmer about 25 years later.

In 1745 a great impetus was given to the study of electrical phenomena by the discovery of the shock which may be produced by the discharge of an electrical condenser through the body. This discovery was first made by Dean von Kleist of the Cathedral of Camin in Pomerania. Dean von Kleist found that he apparently could lead a larger quantity of electricity down a nail into a flask containing mercury or alcohol when he held the flask in his hand than when it stood on a table. In trying to remove the nail from the flask after he had, as he supposed, filled it with electricity, he received a shock. He described this experiment and his sensations on receiving the shock in letters to several scientists in Berlin, Halle and elsewhere. These men failed to verify the experiment, perhaps on account of the poor insulating quality of the glass used, and none of them seemed to attach much importance to the announcement of Father von Kleist.

Within three months a similar discovery was accidentally made in the laboratory of Peter van Musschenbroeck in Leyden. Van Musschenbroeck was one of the leading scientific men of his day and his discoveries were widely published. He communicated his discovery in a letter to Réaumur, in Paris, and it was published in the Mémoires of the Académie in 1746.

The letter to Réaumur was written in January, 1746, and the account of the discovery which it contained is given below as translated in Benjamin's "Intellectual Rise of Electricity."

> I wish to inform you of a new but terrible experiment, which I advise you on no account personally to attempt. I am engaged in a research to determine the strength of Electricity. With this object I had suspended by two blue silk threads, a gun barrel, which received electricity by communication from a glass globe which was turned rapidly on its axis by one operator, while another pressed his hand against it. From the opposite end of the gun barrel hung a brass wire, the end of which entered a glass jar, which was partly full of water. This jar I held in my right hand, while with my left I attempted to draw sparks from the gun barrel. Suddenly I received in my right hand a shock of such violence that my whole body was shaken as by a lightning stroke. The vessel, though of glass, was not broken, nor was the hand displaced by the commotion; but the arm and body were affected in a manner more terrible than I can express. In a word, I believed that I was done for.

This "new and terrible experiment" of van Musschenbroeck's was widely published, and was repeated by scientific men all over Europe, in many cases before large audiences. It is doubtful if any scientific experiment ever created a more profound interest with the public to whom it was demonstrated than did the shock from van Musschenbroeck's electrified vial, and nothing ever seemed a greater mystery than it did until Franklin proposed the explanation which is still accepted. The apparatus by which the shock was produced came to be called generally the Leyden phial or Leyden jar; but in Germany, out of consideration for Dean von Kleist's discovery, it is called the *Kleistschen Flasche.*

Soon after the announcement of van Musschenbroeck's discovery, Benjamin Franklin, of Philadelphia, was presented with a tube of flint glass and was told of some of the wonders of electricity and the properties of the mysterious flask by his friend, Peter Collinson; and he at once began the series of electrical experiments, the results of which have profoundly modified all electrical theories from that time until the present, and which seem destined to determine to a large degree the electrical theories of the future.

Franklin's original discoveries were not more numerous than those of Stephen Gray, though he discovered the effect of points in collecting or discharging electricity, proved the identity of atmospheric and frictional electricity, discovered that bodies within a charged hollow conductor will take no charge from the inner surface of the charged conductor and explained the phenomena of the mysterious flask of von Kleist and van Musschenbroeck; but Franklin proposed a physical interpretation of the phenomena of electricity which received almost universal acceptance at the time, and which now, since several other theories have been tried and have proved unsatisfactory, seems destined again to become the fundamental theory.

It may be interesting to know that the theory of a single electric fluid as the cause of both kinds of electrification discovered by du Fay was proposed almost simultaneously by Franklin in Philadelphia and by William Watson in London, and from virtually the same experiment. Franklin announced his theory in a letter to Peter Collinson, dated June 1, 1747. After speaking of two men insulated on cakes of wax and electrifying themselves, one from rubbing a glass tube and the other from holding his knuckles near to the rubbed tube, while a third man stands on the floor near them, he says:

> These appearances we attempt to account for thus: We suppose, as aforesaid, that electrical fire is a common element, of which every one of the three persons above mention has his equal share before any operation is begun with the tube. A, who stands on wax and rubs the tube, collects the electrical fire from himself into the glass; and his communication with the common stock being cut off by the wax, his body is not again immediately

supplied. B, (who stands on wax likewise) passing his knuckle along near the tube, receives the fire which was collected by the glass from A; and his communication with the common stock being likewise cut off, he retains the additional quantity received. To C, standing on the floor, both appear to be electrified: for he having only the middle quantity of electrical fire, receives a spark upon approaching B, who has an over quantity; but gives one to A, who has an under quantity. If A and B approach to touch each other, the spark is stronger, because the difference between them is greater: after such touch there is no spark between either of them and C, because the electrical fire in all is reduced to the original quantity.

It may not be without interest to compare this concise explanation with the much more labored one proposed by Watson for the same phenomenon. Watson refers to an observation that had been made that a man standing on wax and holding his hand on a rotating glass globe could take no appreciable charge so long as the globe was insulated and held at a distance from other conductors, but would become charged if a conductor or another person, either insulated or uninsulated, should draw off the charge from the glass.

Watson's discussion of this experiment is given in Volume 45 of the *Philosophical Transactions of the Royal Society*, and is, in part as follows:

1. That what we call Electricity is the Effect of a very subtil and elastic Fluid, diffused throughout all Bodies in Contact with the terraqueous Globe (those Substances hitherto termed Electrics *per se* probably excepted), and everywhere, in its natural State of the same Degree of Density.

2. That this Fluid manifests itself only, when Bodies capable of receiving more thereof than their natural Quantity are properly disposed for that Purpose; and that then, by certain known Operations, its Effects shew themselves by attracting and repelling light Substances, by a snapping Noise, Sparks of Fire &c. directed towards other Bodies, having only their natural Quantity, or, at least, a Quantity less than those Bodies from which the Snappings, &c. proceed.

3. That no Snapping is observed in bringing any two Bodies near each other, in which the Electricity is of the same Density, but only in those Bodies in which the Density of the Fluid is unequal.

4. That this snapping is greater or less, in proportion to the different Densities of the Electricity in Bodies brought near each other, and by which Snapping each of them becomes of the same Standard.

5. That Glass, and other Bodies which we call Electrics *per se,* have the Property of taking this Fluid from one Body, and conveying it to another, and that in a Quantity sufficient to be obvious to all our Senses.

6. That in the Experiment in question, the Reason why no Snapping is observed by a Person upon the Floor touching him who rubs the Globe with his hands standing on Wax, without at the same time some other Non-electric supported by Originally Electrics, or otherwise being in contact with the Globe, is owing to whatever Part of this Man's natural Quantity of Electricity, taken from himself by the Globe in Motion, being restored to him again by the Globe in its Revolutions; there not being any other Non-electric near enough to communicate the Electricity to; and therefore, in this Situation, the Electricity of the Man suffers no diminution of its Density.

> 7. That the fact is otherwise, when everything else being as before, either a Gun-barrel suspended in Silk Lines, or a Man supported by Wax, or such like, is placed near the Globe in Motion; because then, whatever part of the Electricity of the Person rubbing is taken from him, is communicated either to the other Man or the Gun-barrel, these, from their Situation, being the first Non-electrics, to which Electricity taken from the Person can be communicated.
>
> 8. That under these Circumstances, as much Electricity as is taken from the Person rubbing is given to the other; by which means the Electricity of the first Man is more rare than it naturally was, and that of the last Man more dense.
>
> 9. That the Electricity in either of these Persons is in a very different State of Density from what it naturally was, or from that of any Person standing upon the Earth; this last being in a middle State between the two other Persons; that is, he has not his Electricity so rare as the Man rubbing the Globe, nor so dense as that of him supported by Electrics *per se,* and touching the Equator of the Globe.
>
> 10. That therefore the same Effect, a Snapping, is observed upon bringing any Non-electric near either of these Persons, from very different Causes: For it is apprehended, that, by bringing the Non-electric near him, whose Electricity is more rare, this Snapping restores to him what he had lost; and that by bringing it near him, whose Electricity is more dense, it takes of his Surcharge, by which means their original Quantity is restored to each.

Watson then refers to the explanation of the same phenomenon by Franklin, with which he had been made acquainted after the presentation of his paper to the Royal Society. Thus he says:

> At this time I am tne more particular concerning the Solution of this singular Appearance as Mr. *Collinson,* a worthy member of this Society, has received a Paper concerning Electricity from an ingenious Gentleman, Mr. *Franklin,* a Friend of his in *Pennsylvania.* This Paper, dated June 1, 1747, I very lately perused, by Favour of our most worthy *President.* Among other curious Remarks, there is a like Solution of this Fact; for though this Gentleman's Experiment was made with a Tube instead of a Globe, the Difference is in no-ways material. As this Experiment was made, and the Solution thereof given upon the other Side of the *Atlantic Ocean* before this gentleman could possibly be acquainted with our having observed the same Fact here, and as he seems very conversant in this part of Natural Philosophy, I take the Liberty of laying before you his own Words.

Then follows Franklin's explanation of the experiment as we have already quoted it.

Franklin's theory of the relation of electricity to material bodies is more fully given in a letter to Peter Collinson under date of July 29, 1750, the year of the publication of Watson's paper. He says:

> 1) The electrical matter consists of particles extremely subtile, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any perceptible resistance.
>
> 2) If any one should doubt whether the electrical matter passes through the substance of bodies, or only over or along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him.

3) Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former mutually repel each other. Hence the appearing divergency in a stream of electrified effluvia.

4) But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter.

Franklin introduced the use of the algebraic signs + and — to indicate the electrical conditions which Watson referred to as denser or rarer electrical states. Thus a body which contained a greater amount of the electrical fluid than it would contain if in electrical contact with the earth was said by Franklin to have a + charge, and one which contained less of the fluid than it would naturally take from the earth was said to have a — charge. From this point of view, the body with a + charge would give electricity to the earth and a body with a — charge would take electricity from the earth if put into electrical contact with it.

Cavendish used the term "pressure" to indicate the same idea. He regarded the electrical fluid in all bodies as under an external pressure and as always flowing in the direction of least pressure. A body with a + charge would then be one in which the electrical fluid was under greater pressure than in the earth, and a body with a — charge as one whose electrical fluid was under a less pressure than the earth's electrical fluid. If the electrical fluid is regarded as compressible, as it must have been by Watson, the + condition would indicate both an increased pressure and an increased density.

All of these concepts assumed an electrified earth, and, as was shown in the previous paper, it was upon the assumption of an electrified earth that Cavendish, and probably Aepinus, undertook to prove the absence of an electrical atmosphere about charged bodies.

The concept of an electrically neutral earth seems to be due to Robert Symmer, in England. In 1759, during Franklin's residence in England, Symmer borrowed some electrical apparatus from him and repeated some of his experiments. As a result of these experiments, he came to a different opinion as to the nature of electrification from the one proposed by Franklin but failed to convert Franklin to his point of view.

In Volume 51 of the *Philosophical Transactions* is a group of four papers by Symmer in which he gives his reasons for believing in two electrical fluids. Of the two principal arguments which he proposes, one is derived from the sensation experienced when the two coatings of a weakly charged Leyden jar are touched by the fingers of one hand. In this case, Symmer says the sensation is that of a shock, or blow, upon the fingers touching both coatings of the jar, with no distinction to indicate that the electricity strikes from one coating rather than from the other.

The other argument is based upon the fuzzy appearance on both sides of a card or of several sheets of paper of the perforation made by a single electric spark, "indicating that the electric fluid has either entered or left both sides," and upon the effect of a spark discharge through a number of sheets of paper with a sheet of tin-foil between them. In this case the tin-foil may not be perforated and the holes made by the spark on opposite sides of the tin-foil may not meet opposite the same point in the foil. In this case there is a little dent in the tin-foil opposite both perforations, indicating that the tin-foil has been struck from opposite sides in the two cases.

After referring to the apparent difficulty of explaining these phenomena by a single electric fluid, Symmer sums up his case as follows:

> On the other hand, it is my opinion that there are two electrical fluids (or emanations of two distinct electrical powers) essentially different from each other; that electricity does not consist in the efflux and afflux of those fluids, but in the accumulation of the one or the other in the body electrified; or, in other words, it consists in the possession of a larger portion of the one or of the other power, than is requisite to maintain an even balance within the body; and, lastly, that according as the one or the other power prevails, the body is electrified in one or in another manner.

It will be seen that Symmer has added to du Fay's notion of two electricities the assumption that all bodies in their natural state possess both kinds but in such quantities that their individual effects are neutralized.

It is interesting to know that Franklin was ignorant of du Fay's discovery when he proposed his theory of a single electric fluid. Later, his friend, Mr. Kinnersly, of Boston, who had taken part in some of Franklin's work, made the discovery that the electricity induced by the friction of the hand on a sulphur globe would discharge the electricity induced in the same way on a glass globe. Thus, if he charged a Leyden jar by sparks from a rubbed glass globe and then allowed a rubbed sulphur globe to spark into it, he found that the jar was first discharged and then, if the sparking were kept up, became charged again. He also found that the jar remained discharged if the glass globe and the sulphur globe were allowed to spark into it at the same time. This caused him to inquire of Franklin whether the glass, or the sulphur, acquired a + charge when rubbed.

Franklin concluded for several reasons, the most important of which seems to have been the different character of the brush discharge of the two, that glass took the excess charge from the body rubbing it, while sulphur gave off electricity to the rubber. Thus, the brush discharge from a positively electrified body is longer and more diverging than from a negatively electrified body. Franklin also observed that the "electric wind" given off from a point is stronger from a body electrified from glass than one electrified from sulphur. He concluded for these reasons that the electric fluid was escaping from the charged glass and was being collected by the charged sulphur.

Franklin did not attach much importance to his attempted identification of the + and — electric conditions. Priestley says that one question which greatly puzzled Franklin was why negatively electrified bodies should repel each other, since his theory was that particles of electric fluid repel each other while the particles of material bodies attract each other. It would seem from these hypotheses that two bodies containing a deficiency of the electric fluid should attract each other.

The opinion that the electric fluid is attracted by the particles of material bodies led to the modification of Franklin's theory by the introduction of the assumption that the particles of material bodies, when free from electricity, must also repel each other. In making this assumption, an important discovery made by Stephen Gray was seemingly overlooked, and though this observation has been repeated thousands of times it seems still to be overlooked by most writers on electrical theory. Gray found that a hollow box of wood when charged seemed to take as great a charge as a solid block of the same size, and every student of electricity now knows that a hollow conductor, no matter how thin its walls, has the same electric capacity as a solid conductor of the same shape and size. If the particles of the electric fluid were attracted by the particles of the conductor, this would not be the case.

The Franklinian theory, even when modified by the assumption of a repulsion between the atoms of material bodies still differed in important respects from the two fluid theory of du Fay and Symmer, since in the latter theory in its final form an electric discharge always consisted in the passage of both kinds of electricity in opposite directions between the two conductors. This theory as it was developed prior to 1767 is described by Priestley, in his "History of Electricity," as follows:

> To show my absolute impartiality, I shall, notwithstanding the preference I have given to Dr. Franklin's theory, endeavor to represent this to as much advantage as possible, and to do it more justice than has yet been done to it, even by Mr. Symmer himself; who, as I observed before, has fallen into some mistakes in his application of it. Indeed, hitherto very little pains has been taken with this theory, nor has it been extended to any great variety of phenomena.
>
> Let us suppose then, that there are two electric fluids, which have a strong chymical affinity with each other, at the same time that the particles of each are as strongly repulsive of one another. Let us suppose these two fluids, in some measure, equally attracted by all bodies, and existing in intimate union in their pores, and while they continue this union to exhibit no mark of their existence. Let us suppose that the friction of any electric produces a separation of these two fluids, causing (in the usual method of electrifying) the vitreous electricity of the rubber to be conveyed to the conductor, and the resinous electricity of the conductor to be conveyed to the rubber. The rubber will then have a double share of the resinous electricity, and the conductor a double share of the vitreous; so that, upon this hypothesis, no substance

> whatever can have a greater or less quantity of electric fluid at different times; the quality of it only can be changed.
>
> The two electric fluids, being thus separated, will begin to show their respective powers, and their eagerness to rush into reunion with one another. With whichsoever of these fluids a number of bodies are charged, they will repel one another, they will be attracted by all bodies which have a less share of that particular fluid with which they are loaded, but will be much more strongly attracted by bodies which are wholly destitute of it, and loaded with the other. In this case they will rush together with great violence.
>
> Upon this theory, every electric spark consists of both the fluids rushing contrary ways, and making a double current. When, for instance, I present my finger to a conductor loaded with vitreous electricity, I discharge it of part of the vitreous, and return as much of the resinous, which is supplied to my body from the earth. Thus both the bodies are unelectrified, the balance of the two powers being perfectly restored.
>
> When I present the Leyden phial to be charged, and, consequently, connect the coating of one of its sides with the rubber, and that of the other with the conductor, the vitreous electricity of that side which is connected with the conductor is transmitted to that which is connected with the rubber, which returns an equal quantity of its resinous electricity; so that all the vitreous electricity is conveyed to one of the sides and all the resinous to the other. These two fluids, being thus separated, attract one another very strongly through the thin substance of the intervening glass, and rush together with great violence, whenever an opportunity is presented, by means of proper conductors. Sometimes they will force a passage through the substance of the glass itself; and, in the meantime, their mutual attraction is stronger than any force that can be applied to draw away either of the fluids separately.

Thus it is seen that the two fluid theory involves more assumptions than does the theory of a single fluid. In the two fluid theory the notion of combined, or neutralized, electricities seems to be necessary to account for some of the commonest phenomena of electrification. Maxwell speaks of this necessity as follows:

> The introduction of the two fluids permits us to consider the negative electrification of A and the positive electrification of B as the effect of *any one* of three different processes which would lead to the same result. We have already supposed it produced by the transfer of P units of positive electricity from A to B, together with the transfer of N units of negative electricity from B to A. But if $P+N$ units of positive electricity had been transferred from A to B, or if $P+N$ units of negative electricity had been transferred from B to A, the resulting "free electricity" on A and B would have been the same as before, but the quantity of "combined electricity" in A would have been less in the second case and greater in the third than it was in the first.
>
> It would appear therefore, according to this theory, that it is possible to alter not only the amount of free electricity in a body, but the amount of combined electricity. But no phenomena have ever been observed in electrified bodies which can be traced to the varying amount of their combined electricities. Hence either the combined electricities have no observable properties or the amount of the combined electricities is incapable of variation. The first of these alternatives presents no difficulty to the mere mathematician, who attributes no properties to the fluids except those of attraction and repulsion, for he conceives the two fluids simply to annul one another, like $+e$ and $-e$, and their combination to be a true mathematical zero. But to those who cannot use the word fluid without thinking of a substance it is difficult to conceive how the combination of the two fluids can have no properties at all, so that the addition of more or less of the combination to a body shall not in any way affect it, either by increasing its mass or its weight, or altering some of its other properties. Hence it has been supposed by some, that in every process of electrification exactly equal quantities of the two fluids are transferred in opposite directions, so that the total quantity of the two fluids in any body taken together remains always the same. By this new

law they 'contrive to save appearances,' forgetting that there would have been no need of the law except to reconcile the "Two Fluids" theory with facts, and to prevent it from predicting non-existent phenomena.

In the one fluid theory as stated by Maxwell the notion of saturation takes the place of neutralization. Thus Maxwell says:

> If the quantity of electric fluid in a body is such that a particle of the fluid outside the body is as much repelled by the electric fluid in the body as it is attracted by the matter of the body, the body is said to be saturated. If the quantity of fluid in the body is greater than that required for saturation, the excess is called the Redundant fluid and the body is said to be Overcharged. If it is less, the body is said to be Undercharged, and the quantity of fluid which would be required to saturate it is sometimes called the Deficient fluid.

The Franklinian theory as modified by the addition of the hypothesis that the particles of ordinary matter, as well as the particles of the electric fluid, must be self repellent lasted well into the 19th Century. Its replacement by the two fluid theory seems finally to have been due to its assumption of an electric attraction between the particles of the electric fluid and the particles of material bodies.

Thus Dr. Thomas Thomson, in his *Outline Of The Sciences of Heat And Electricity*, published in 1830 and just before the important work of Faraday, says:

> The second datum, that the electric fluid is attracted by matter with a force inversely as the square of the distance, is also inconsistent with the electrical phenomena. For the quantity of electricity accumulated in bodies is always proportional to the extent of their surface, and not to the quantity of matter in them, as would be the case if any attraction or affinity existed between them. All substances, whatever their nature may be, are capable of receiving the same quantity of electricity, provided the extent of their surfaces be equal. And, finally, it has been shown that electricity accumulates only on the surfaces of bodies, and that nothing but the pressure of the ambient atmosphere prevents it from making its escape.

This objection to the single fluid theory seems valid, but it should also apply equally well to the theory of two fluids when an attraction is assumed between either, or both, the fluids and the particles of material bodies. That is, this objection is not more fatal to a theory of a single fluid than to one of two fluids, and cannot be looked upon as deciding between them. This fact seems to have been implicitly recognized by the physicists of that day, since it came to be assumed as a part of the accepted theory of the day that no attraction or affinity exists between either of the electric fluids and material bodies.

But if this be assumed, how may an electrified body attract an unelectrified body? Or how may two oppositely electrified bodies attract each other? This question is asked and answered by Dr. Thomson as follows:

> But if there be no affinity or attraction between electricity and matter, it may appear, at first sight, difficult to account for the fact that when bodies are excited, that is, contain a super-abundance of electricity, they *attract* or *repel* each other with forces varying inversely as the square of the distance; bodies having the same kind of electricity repelling, and those having different

> kinds attracting each other. But this apparent difficulty admits of a very simple explanation.
>
> If we suppose two excited and insulated spheres placed at a small distance from each other, it is obvious that the only forces which can occasion the motion of the bodies, are the mutual attraction or repulsion of the fluid in the one, to the fluid in the other. For the repulsions exercised by the particles of fluid in each body on one another, can have no effect in producing a motion in the center of gravity of either body. If the two spheres consist of non-conducting matter, the unknown power which gives them the non-conducting property, will prevent the escape of the electricity from each. Therefore the mutual attractions and repulsions of the fluids, as they cannot escape from the matter, may be supposed to carry the matter along with them, and thus to cause the globes to approach or recede, according as they are charged with different kinds of electricity, or with the same kind.
>
> When an excited conducting body is insulated the superinduced electricity forms a coating on its surface, and (if we suppose the body spherical) the thickness of this coating will be everywhere the same. This electricity presses upon the ambient air, which prevents it from making its escape. The excited sphere, in consequence of this action of the electricity, which is proportional to the square of its thickness, will be less pressed upon by the surrounding atmosphere, than if it were not excited. But as the pressure, though diminished, is everywhere equal, there will be no tendency of the sphere to move from its place. Let us suppose the conducting sphere to be charged with positive electricity, and let us conceive a mass of sealing wax or gum lac, charged negatively, to approach it, a portion of the combined electricity natural to the sphere, will be decomposed. The positive portion will accumulate on the surface of the sphere next the mass of sealing wax, being attracted by its negative electricity. The superabundant positive electricity already in the sphere will accumulate at the same surface for the same reason. While the decomposed negative electricity will accumulate at the opposite surface of the sphere, being repelled by the negative electricity of the sealing wax. Thus the coating of electricity next the sealing wax will become thicker than before, while the coating at the greatest distance will become thinner. Hence the electricity in the part of the sphere next the sealing wax will press more upon the air than before, while the air will press more than before upon that surface of the sphere which is farthest from the sealing wax. Both of these pressures have a tendency to cause the sphere to move towards the sealing wax, and if the weight of the sphere be sufficiently small it will move accordingly.

It seems impossible that any one with even a smattering of mechanics could take the above explanation seriously, much less accept it as "a very simple explanation," but Dr. Thomson evidently took it seriously, and he proceeded immediately after the above quotation to put it into mathematical form. And Dr. Thomson was a very eminent scientific man, professor of chemistry in Glasgow, fellow of the Royal Societies of London and Edinburgh and member of most of the learned societies of England and the Continent. It accordingly is probable that this represents the best explanation at that time available of this difficult electrical problem.

De La Rive, in his great treatise on Electricity published twenty-three years later, is still wrestling with this problem. He still seemed satisfied with the explanation which Thomson had given with regard to insulators, that while their particles could have no attraction for electricity, still "The unknown power which gives them the non-conducting property will prevent the escape of electricity from each," and accordingly that they may be pulled together by the attraction of their electric fluids; but in the meantime Becquerel, Sir W. Snow Harris, and others, had repeated the discovery made one hundred years before by Hauksbee and Stephen Gray that electric attraction and repulsion may take place in the best air pump vacuum. De la Rive, referring to this experiment, says:

> Sir W. Snow Harris has observed that the attractions and repulsions between electrifed bodies take place in vacuo as they do in air; a further proof of the error we should commit by admitting the atmospheric pressure to play a part in the phenomena. This fact, on the other hand, is very well explained by admitting that the electricities are retained, in the portions of the surfaces where they are distributed, by the insulating effect of the film of air that remains adjacent, and in no degree by atmospheric pressure: once retained at the surface by this cause, as they would have been by a coating of varnish, they are no longer able to obey their mutual attraction or repulsion, except by drawing with them the bodies themselves, if their mass is not too great. This explanation, even though it should not be based upon observations made in vacuo, would seem to us in every case preferable to that in which atmospheric pressure is made to intervene; this intervention being implicitly founded on a purely hypothetical idea, namely, that electricity is a fluid of the same kind, and about the same tenuity as air and gases.
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> Further, while still believing that the electric effects observed in vacuo, as well as others no less curious, of which we shall speak hereafter, are due to the film of air that remains adhering to the surface of bodies, we by no means wish to pretend that conducting bodies have not for themselves the property of preserving, or rather *coercing* on their surface a certain dose of electricity, feeble, it is true, but nevertheless sensible.

At the time of writing of de la Rive's treatise the interest in statical electrical phenomena was declining, owing to Volta's discovery of the electric current at the end of the 18th century and the brilliant discoveries of Davy and Faraday in electrochemistry and of Oersted, Ampère and Faraday in electromagnetic induction. The question as to how two oppositely electrified bodies may attract each other while there is no attraction between the particles of the electric fluid and material particles was overlooked for the time being. Then the electric theory of Faraday was at this time coming to the front in English speaking countries, and from the point of view of this theory this question could have no significance, since no electric fluid of any kind was assumed in the Faraday theory.

Since the discovery and isolation of the electric fluid by J. J. Thomson and his followers at the close of the 19th century, the question as to what part this fluid takes in the attraction or repulsion of electrified bodies has assumed its earlier importance, but the electrical theory of the present time is not concerned with the physical interpretation of phenomena, but only with the mathematical statement of their quantitative relations, and all qualitative relations are being ignored. The problem of the nature of electric attraction accordingly remains in the hopeless condition in which it was left by de la Rive.